

# Differential cross sections ${}^4\text{He}(\gamma, p){}^3\text{H}$ and ${}^4\text{He}(\gamma, n){}^3\text{He}$ reactions in the range of the photon energies up to the threshold of the meson production

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## Abstract

Differential cross sections two-body  $(\gamma, p)$  and  $(\gamma, n)$  reactions of the  ${}^4\text{He}$  nucleus disintegration were measured using the bremsstrahlung beam of photons at the KIPT linac LEA-300 at the maximum energy  $E_{\gamma}^{max} = 150$  MeV Arkatov *et al.* [Sov.J.Nucl.Phys.10, 639 (1970), [Sov.J.Nucl.Phys.19, 598 (1974)]. The reaction products were detected in a diffusion chamber placed in the magnetic field. Later, this experiment was processed for the second time Nagorny *et al.* [Sov.J.Nucl.Phys. 53, 228 (1991); Yad.Fiz. 53, 365 (1991)]. At this the total number of handled events of  ${}^4\text{He}$  disintegration was made up  $\sim 3 \cdot 10^4$  per reaction channel. The differential cross sections were measured with a 1 MeV step up to a photon energy of 45 MeV, and with a greater step at higher energies. The step in the measurements of the polar angle of nucleon emission was  $10^\circ$  in the c.m.s. Authors published data on differential cross sections only at  $E_{\gamma}=22.5, 27.5, 33.5, 40.5, 45$ , and 49 MeV photon energies.

S.I.Nagorny, Yu.A.Kasatkin, I.K.Kirichenko, A.A.Zayats and V.N.Gur'ev took part in the theoretical analysis of these data. Lyakhno *et al.* [Nucl. Phys.A 781, 306 (2007)] used these data for combined analysis with data on cross section asymmetry with linear polarized photons. Unfortunately, most authors of these data already died. The mentioned above data are kept only by Yu. Lyakhno. Unfortunately, part of the data of the range of the photons energies  $49 \leq E_{\gamma} \leq 57$  MeV  ${}^4\text{He}(\gamma, p){}^3\text{H}$  reactions was lost. After the discussion with the authors Yu. Lyakhno was assigned to put all the saved data into the arXiv.

I set my sincere gratitude to authors of these data and also to I.V. Dogyust for the help in the designing of this publication.

The cross sections are set in the  $\mu\text{b}/\text{sr}$ .

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**T a b l e 1:**  ${}^4\text{He}(\gamma, n){}^3\text{He}$  reaction

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	22-23	23-24	24-25	25-26	26-27	27-28
0-10	$3.5 \pm 2.4$	$4.5 \pm 2.6$	$7.5 \pm 3.1$	$4 \pm 1.6$	$2.1 \pm 1.5$	$10.1 \pm 3.4$
10-20	$6.9 \pm 3.5$	$9.0 \pm 3.7$	$21.2 \pm 5.2$	$21.5 \pm 3.8$	$24.3 \pm 5.1$	$12.4 \pm 3.7$
20-30	$20.7 \pm 6.0$	$39.2 \pm 7.7$	$42.5 \pm 7.3$	$53.1 \pm 6.0$	$57.0 \pm 7.8$	$49.6 \pm 7.5$
30-40	$29.4 \pm 7.1$	$60.3 \pm 9.5$	$66.2 \pm 9.1$	$78.7 \pm 7.3$	$87.7 \pm 9.6$	$78.8 \pm 9.4$
40-50	$51.9 \pm 9.5$	$87.5 \pm 11.5$	$97.5 \pm 11.0$	$113.0 \pm 8.7$	$95.1 \pm 10.0$	$98.0 \pm 10.5$
50-60	$32.8 \pm 7.5$	$122.2 \pm 13.6$	$155.0 \pm 13.9$	$133.2 \pm 9.5$	$151.0 \pm 12.6$	$144.2 \pm 12.7$
60-70	$72.6 \pm 11.2$	$93.5 \pm 11.9$	$156.2 \pm 14.0$	$160.1 \pm 10.4$	$172.2 \pm 13.5$	$147.5 \pm 12.9$
70-80	$64.0 \pm 10.5$	$107.1 \pm 12.7$	$171.2 \pm 14.6$	$166.1 \pm 10.6$	$174.3 \pm 13.6$	$171.2 \pm 13.9$
80-90	$69.1 \pm 10.9$	$137.2 \pm 14.4$	$177.5 \pm 14.9$	$193.7 \pm 11.4$	$226.0 \pm 15.5$	$190.3 \pm 14.6$
90-100	$67.4 \pm 10.8$	$146.3 \pm 14.9$	$165.0 \pm 14.4$	$202.4 \pm 11.7$	$194.4 \pm 14.3$	$199.4 \pm 15.0$
100-110	$64.0 \pm 10.5$	$114.6 \pm 13.1$	$141.2 \pm 13.3$	$174.9 \pm 10.8$	$192.2 \pm 14.3$	$181.3 \pm 14.3$
110-120	$81.2 \pm 11.9$	$126.7 \pm 13.8$	$133.7 \pm 12.9$	$138.5 \pm 9.7$	$195.4 \pm 14.4$	$166.7 \pm 13.7$
120-130	$53.6 \pm 9.6$	$110.1 \pm 12.9$	$103.7 \pm 11.4$	$131.8 \pm 9.4$	$152.1 \pm 12.7$	$149.9 \pm 13.0$
130-140	$32.8 \pm 7.5$	$101.1 \pm 12.3$	$91.2 \pm 10.7$	$87.4 \pm 7.7$	$119.4 \pm 11.2$	$116.0 \pm 11.4$
140-150	$22.5 \pm 6.2$	$43.7 \pm 8.1$	$71.2 \pm 9.4$	$55.8 \pm 6.1$	$88.7 \pm 9.7$	$69.8 \pm 8.9$
150-160	$12.1 \pm 4.6$	$34.7 \pm 7.2$	$42.5 \pm 7.3$	$28.9 \pm 4.4$	$40.1 \pm 6.5$	$39.4 \pm 6.7$
160-170	$3.5 \pm 2.4$	$16.6 \pm 5.0$	$13.7 \pm 4.1$	$21.5 \pm 3.8$	$22.2 \pm 4.8$	$13.5 \pm 3.9$
170-180	$3.5 \pm 2.4$	$3.0 \pm 2.1$	$7.5 \pm 3.1$	$7.4 \pm 2.2$	$4.2 \pm 2.1$	$9.0 \pm 3.2$

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	28-29	29-30	30-31	31-32	32-33	33-34
0-10	$7.7 \pm 2.9$	$4.7 \pm 2.3$	$9.0 \pm 2.5$	$7.4 \pm 2.4$	$3.3 \pm 1.6$	$7.5 \pm 2.5$
10-20	$13.2 \pm 3.8$	$22.1 \pm 5.1$	$20.2 \pm 3.7$	$17.8 \pm 3.6$	$16.3 \pm 3.7$	$15.9 \pm 3.7$
20-30	$53.0 \pm 7.6$	$51.0 \pm 7.6$	$35.4 \pm 5.0$	$37.2 \pm 5.3$	$32.7 \pm 5.2$	$32.7 \pm 5.2$
30-40	$67.3 \pm 8.6$	$75.7 \pm 9.4$	$57.7 \pm 6.3$	$54.3 \pm 6.3$	$42.5 \pm 5.9$	$41.9 \pm 5.9$
40-50	$118.1 \pm 11.4$	$101.3 \pm 10.9$	$88.3 \pm 7.8$	$86.2 \pm 8.0$	$72.7 \pm 7.7$	$75.4 \pm 7.9$
50-60	$124.7 \pm 11.7$	$132.7 \pm 12.4$	$116.1 \pm 9.0$	$109.2 \pm 9.0$	$117.7 \pm 9.8$	$99.7 \pm 9.1$
60-70	$155.6 \pm 13.1$	$165.3 \pm 13.9$	$139.7 \pm 9.9$	$143.4 \pm 10.3$	$125.1 \pm 10.1$	$132.3 \pm 10.5$
70-80	$183.2 \pm 14.2$	$140.9 \pm 12.8$	$150.8 \pm 10.2$	$139.7 \pm 10.2$	$144.7 \pm 10.9$	$118.0 \pm 9.9$
80-90	$174.4 \pm 13.9$	$199.1 \pm 15.2$	$169.6 \pm 10.9$	$142.7 \pm 10.3$	$151.2 \pm 11.1$	$149.1 \pm 11.2$
90-100	$190.9 \pm 14.5$	$188.6 \pm 14.8$	$160.6 \pm 10.6$	$141.2 \pm 10.2$	$148.8 \pm 11.0$	$164.2 \pm 11.7$
100-110	$170.0 \pm 13.7$	$181.6 \pm 14.5$	$164.0 \pm 10.7$	$155.3 \pm 10.7$	$135.7 \pm 10.5$	$170.0 \pm 11.9$
110-120	$176.6 \pm 14.0$	$144.3 \pm 13.0$	$143.2 \pm 10.0$	$170.9 \pm 11.3$	$144.7 \pm 10.9$	$119.8 \pm 10.0$
120-130	$133.6 \pm 12.1$	$156.0 \pm 13.5$	$137.6 \pm 9.8$	$128.6 \pm 9.8$	$141.4 \pm 10.8$	$120.6 \pm 10.1$
130-140	$109.3 \pm 11.0$	$95.5 \pm 10.5$	$103.6 \pm 8.5$	$98.1 \pm 8.5$	$94.8 \pm 8.8$	$92.1 \pm 8.8$
140-150	$83.9 \pm 9.6$	$76.8 \pm 9.5$	$79.2 \pm 7.4$	$74.3 \pm 7.4$	$91.5 \pm 8.7$	$70.4 \pm 7.7$
150-160	$48.6 \pm 7.3$	$50.1 \pm 7.6$	$58.4 \pm 6.4$	$44.6 \pm 5.8$	$57.2 \pm 6.8$	$42.7 \pm 6.0$
160-170	$13.2 \pm 3.8$	$26.8 \pm 5.6$	$31.3 \pm 4.7$	$17.1 \pm 3.6$	$28.6 \pm 4.8$	$16.8 \pm 3.7$
170-180	$8.8 \pm 3.1$	$4.7 \pm 2.3$	$4.2 \pm 1.7$	$4.5 \pm 1.8$	$9.0 \pm 2.7$	$8.4 \pm 2.6$

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	34-35	35-36	36-37	37-38	38-39	39-40
0-10	12.3±3.6	12.7±3.3	4.9±2.2	6.1±2.5	8.9±3.1	2.5±1.8
10-20	7.2±2.7	19.5±4.1	9.9±3.1	13.3±3.7	16.7±4.3	10.0±3.5
20-30	36.0±6.1	38.9±5.7	25.6±5.0	25.5±5.1	27.8±5.6	22.4±5.3
30-40	49.3±7.1	49.9±6.5	49.3±7.0	53.1±7.4	51.2±7.5	41.1±7.2
40-50	55.5±7.5	72.0±7.8	69.0±8.2	67.4±8.3	57.9±8.0	59.8±8.6
50-60	85.3±9.4	106.7±9.5	66.0±8.1	77.6±8.9	73.4±9.0	84.7±10.3
60-70	108.9±10.6	111.7±9.7	79.8±8.9	82.7±9.2	75.7±9.2	76.0±9.7
70-80	112.0±10.7	118.5±10.0	112.3±10.5	104.2±10.3	99.0±10.5	102.1±11.3
80-90	113.0±10.8	148.1±11.2	113.3±10.6	105.2±10.4	110.2±11.1	88.4±10.5
90-100	117.1±11.0	149.8±11.3	112.3±10.5	94.0±9.8	104.6±10.8	105.8±11.5
100-110	139.7±12.0	140.5±10.9	122.2±11.0	126.6±11.4	112.4±11.2	105.8±11.5
110-120	123.3±11.3	116.8±9.9	130.1±11.3	137.9±11.9	101.3±10.6	76.0±9.7
120-130	108.9±10.6	129.5±10.5	103.5±10.1	103.2±10.3	91.2±10.1	73.5±9.6
130-140	107.9±10.5	96.5±9.0	82.8±9.0	65.4±8.2	71.2±8.9	73.5±9.6
140-150	66.8±8.3	66.9±7.5	69.0±8.2	61.3±7.9	62.3±8.3	53.5±8.2
150-160	33.9±5.9	56.7±6.9	49.3±7.0	34.7±6.0	32.3±6.0	22.4±5.3
160-170	20.5±4.6	27.1±4.8	24.6±4.9	15.3±4.0	14.5±4.0	19.9±5.0
170-180	9.2±3.1	7.6±2.5	5.9±2.4	7.1±2.7	4.5±2.2	5.0±2.5

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	40-41	41-42	42-43	43-44	44-46	46-48
0-10	5.9±2.9	4.5±1.6	3.6±1.6	5.0±1.8	0.8±0.8	4.2±1.9
10-20	5.9±2.9	11.3±2.5	10.8±2.8	10.6±2.6	11.9±3.1	14.1±3.4
20-30	32.4±6.9	25.4±3.8	27.4±4.4	22.5±3.8	16.7±3.6	19.1±4.0
30-40	36.9±7.4	41.7±4.9	36.0±5.1	46.9±5.4	26.2±4.6	28.3±4.9
40-50	59.0±9.3	54.7±5.6	54.1±6.2	51.3±5.7	39.7±5.6	50.8±6.5
50-60	75.2±10.5	61.5±5.9	56.2±6.4	64.4±6.3	59.5±6.9	46.6±6.2
60-70	59.0±9.3	78.4±6.7	62.7±6.7	75.1±6.9	42.0±5.8	57.4±6.9
70-80	72.2±10.3	70.5±6.3	78.6±7.5	78.2±7.0	63.4±7.1	66.6±7.4
80-90	89.9±11.5	70.5±6.3	77.1±7.5	102.0±8.0	60.3±6.9	69.9±7.6
90-100	92.9±11.7	70.5±6.3	65.6±6.9	73.8±6.8	58.7±6.8	66.6±7.4
100-110	60.4±9.4	77.3±6.6	70.6±7.1	92.6±7.6	66.6±7.3	46.6±6.2
110-120	92.9±11.7	76.1±6.6	67.0±7.0	75.1±6.9	53.1±6.5	57.4±6.9
120-130	84.0±11.1	63.7±6.0	53.3±6.2	75.1±6.9	39.7±5.6	53.3±6.7
130-140	35.4±7.2	63.7±6.0	48.3±5.9	50.7±5.6	35.7±5.3	32.5±5.2
140-150	31.0±6.8	47.4±5.2	33.9±4.9	45.0±5.3	27.0±4.6	26.6±4.7
150-160	25.1±6.1	27.1±3.9	25.2±4.3	19.4±3.5	15.1±3.5	18.3±3.9
160-170	11.8±4.2	10.2±2.4	8.6±2.5	9.4±2.4	4.8±1.9	12.5±3.2
170-180	2.9±2.1	3.4±1.4	5.8±2.0	6.3±2.0	0.8±0.8	5.0±2.0

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	48-50	50-52	52-54	54-56	56-58	58-60
0-10	2.1 $\pm$ 1.5	3.6 $\pm$ 1.8	1.9 $\pm$ 1.4	4.8 $\pm$ 2.1	0.0 $\pm$ 0.8	0.0 $\pm$ 1.0
10-20	6.2 $\pm$ 2.5	2.7 $\pm$ 1.6	3.9 $\pm$ 1.9	8.6 $\pm$ 2.9	3.2 $\pm$ 1.6	7.0 $\pm$ 2.7
20-30	22.6 $\pm$ 4.8	21.5 $\pm$ 4.4	11.7 $\pm$ 3.4	12.4 $\pm$ 3.4	11.3 $\pm$ 3.0	9.0 $\pm$ 3.0
30-40	28.8 $\pm$ 5.4	34.9 $\pm$ 5.6	13.6 $\pm$ 3.6	10.5 $\pm$ 3.2	22.6 $\pm$ 4.3	16.1 $\pm$ 4.0
40-50	48.3 $\pm$ 7.1	36.7 $\pm$ 5.7	35.9 $\pm$ 5.9	27.6 $\pm$ 5.1	24.2 $\pm$ 4.4	20.1 $\pm$ 4.5
50-60	42.2 $\pm$ 6.6	51.0 $\pm$ 6.8	24.3 $\pm$ 4.9	41.9 $\pm$ 6.3	34.7 $\pm$ 5.3	29.1 $\pm$ 5.4
60-70	45.3 $\pm$ 6.8	40.3 $\pm$ 6.0	28.2 $\pm$ 5.2	31.5 $\pm$ 5.5	33.0 $\pm$ 5.2	23.1 $\pm$ 4.8
70-80	50.4 $\pm$ 7.2	42.1 $\pm$ 6.1	40.8 $\pm$ 6.3	35.3 $\pm$ 5.8	33.9 $\pm$ 5.2	35.2 $\pm$ 5.9
80-90	55.5 $\pm$ 7.6	47.5 $\pm$ 6.5	41.8 $\pm$ 6.4	41.9 $\pm$ 6.3	26.6 $\pm$ 4.6	34.2 $\pm$ 5.9
90-100	50.4 $\pm$ 7.2	50.1 $\pm$ 6.7	34.0 $\pm$ 5.7	34.3 $\pm$ 5.7	27.4 $\pm$ 4.7	37.2 $\pm$ 6.1
100-110	50.4 $\pm$ 7.2	40.3 $\pm$ 6.0	30.1 $\pm$ 5.4	39.1 $\pm$ 6.1	29.8 $\pm$ 4.9	29.1 $\pm$ 5.4
110-120	59.6 $\pm$ 7.8	41.2 $\pm$ 6.1	35.0 $\pm$ 5.8	35.3 $\pm$ 5.8	25.8 $\pm$ 4.6	46.2 $\pm$ 6.8
120-130	40.1 $\pm$ 6.4	39.4 $\pm$ 5.9	29.1 $\pm$ 5.3	29.6 $\pm$ 5.3	18.5 $\pm$ 3.9	25.1 $\pm$ 5.0
130-140	30.0 $\pm$ 5.6	41.2 $\pm$ 6.1	22.3 $\pm$ 4.7	26.7 $\pm$ 5.0	25.0 $\pm$ 4.5	25.1 $\pm$ 5.0
140-150	16.5 $\pm$ 4.1	20.6 $\pm$ 4.3	17.5 $\pm$ 4.1	23.8 $\pm$ 4.8	15.3 $\pm$ 3.5	18.1 $\pm$ 4.3
150-160	11.3 $\pm$ 3.4	14.3 $\pm$ 3.6	11.7 $\pm$ 3.4	17.2 $\pm$ 4.0	10.5 $\pm$ 2.9	9.0 $\pm$ 3.0
160-170	4.1 $\pm$ 2.1	6.3 $\pm$ 2.4	5.8 $\pm$ 2.4	2.9 $\pm$ 1.7	4.8 $\pm$ 2.0	7.0 $\pm$ 2.7
170-180	3.1 $\pm$ 1.8	0.9 $\pm$ 0.9	1.0 $\pm$ 1.0	3.8 $\pm$ 1.9	1.6 $\pm$ 1.1	1.0 $\pm$ 1.0

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	60-62	62-64	64-66	66-68	68-70	70-72
0-10	1.1 $\pm$ 0.8	0.0 $\pm$ 0.7	0.8 $\pm$ 0.8	0.7 $\pm$ 0.7	1.2 $\pm$ 0.9	0.6 $\pm$ 0.6
10-20	6.7 $\pm$ 1.9	7.9 $\pm$ 2.4	0.8 $\pm$ 0.8	3.9 $\pm$ 1.6	1.2 $\pm$ 0.9	7.0 $\pm$ 2.1
20-30	12.2 $\pm$ 2.6	7.9 $\pm$ 2.4	8.3 $\pm$ 2.6	11.2 $\pm$ 2.7	10.5 $\pm$ 2.5	7.0 $\pm$ 2.1
30-40	20.5 $\pm$ 3.4	15.0 $\pm$ 3.3	16.7 $\pm$ 3.7	11.8 $\pm$ 2.8	11.7 $\pm$ 2.7	10.8 $\pm$ 2.6
40-50	27.8 $\pm$ 3.9	21.4 $\pm$ 3.9	15.8 $\pm$ 3.6	10.5 $\pm$ 2.6	12.9 $\pm$ 2.8	12.7 $\pm$ 2.8
50-60	31.7 $\pm$ 4.2	21.4 $\pm$ 3.9	35.9 $\pm$ 5.5	13.8 $\pm$ 3.0	16.0 $\pm$ 3.1	12.7 $\pm$ 2.8
60-70	26.1 $\pm$ 3.8	19.3 $\pm$ 3.7	26.7 $\pm$ 4.7	17.1 $\pm$ 3.4	20.3 $\pm$ 3.5	23.4 $\pm$ 3.9
70-80	25.5 $\pm$ 3.8	25.0 $\pm$ 4.2	32.5 $\pm$ 5.2	25.0 $\pm$ 4.1	16.0 $\pm$ 3.1	29.8 $\pm$ 4.3
80-90	27.2 $\pm$ 3.9	23.6 $\pm$ 4.1	29.2 $\pm$ 4.9	29.6 $\pm$ 4.4	24.6 $\pm$ 3.9	21.5 $\pm$ 3.7
90-100	28.3 $\pm$ 4.0	32.1 $\pm$ 4.8	32.5 $\pm$ 5.2	25.7 $\pm$ 4.1	26.5 $\pm$ 4.0	18.4 $\pm$ 3.4
100-110	26.7 $\pm$ 3.8	27.1 $\pm$ 4.4	32.5 $\pm$ 5.2	20.4 $\pm$ 3.7	17.2 $\pm$ 3.3	22.2 $\pm$ 3.7
110-120	27.2 $\pm$ 3.9	25.7 $\pm$ 4.3	15.8 $\pm$ 3.6	21.7 $\pm$ 3.8	18.5 $\pm$ 3.4	20.3 $\pm$ 3.6
120-130	23.9 $\pm$ 3.6	18.6 $\pm$ 3.6	21.7 $\pm$ 4.3	17.1 $\pm$ 3.4	17.2 $\pm$ 3.3	12.7 $\pm$ 2.8
130-140	21.7 $\pm$ 3.5	15.7 $\pm$ 3.3	14.2 $\pm$ 3.4	13.8 $\pm$ 3.0	16.6 $\pm$ 3.2	13.9 $\pm$ 3.0
140-150	16.1 $\pm$ 3.0	9.3 $\pm$ 2.6	10.8 $\pm$ 3.0	9.9 $\pm$ 2.5	8.0 $\pm$ 2.2	8.9 $\pm$ 2.4
150-160	6.1 $\pm$ 1.8	9.3 $\pm$ 2.6	7.5 $\pm$ 2.5	5.3 $\pm$ 1.9	4.3 $\pm$ 1.6	7.0 $\pm$ 2.1
160-170	5.0 $\pm$ 1.7	4.3 $\pm$ 1.7	4.2 $\pm$ 1.9	2.6 $\pm$ 1.3	4.3 $\pm$ 1.6	3.8 $\pm$ 1.6
170-180	0.6 $\pm$ 0.6	2.1 $\pm$ 1.2	2.5 $\pm$ 1.4	3.3 $\pm$ 1.5	0.6 $\pm$ 0.6	1.9 $\pm$ 1.1

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	72-74	74-76	76-78	78-80	80-85	85-90
0-10	1.9±1.1	0.5±0.5	0.9±0.6	0.5±0.5	0.4±0.4	1.5±0.8
10-20	2.5±1.2	4.6±1.5	3.4±1.2	5.3±1.7	3.7±1.2	1.5±0.8
20-30	5.0±1.8	7.2±1.9	7.3±1.8	8.6±2.1	8.1±1.7	5.3±1.4
30-40	15.0±3.1	10.3±2.3	6.9±1.7	11.2±2.4	7.0±1.6	5.3±1.4
40-50	20.6±3.6	9.2±2.2	13.4±2.4	15.5±2.9	11.7±2.1	10.6±2.0
50-60	15.6±3.1	20.5±3.2	15.1±2.5	14.4±2.8	14.7±2.3	14.8±2.4
60-70	19.4±3.5	14.9±2.8	16.4±2.7	20.8±3.3	12.5±2.1	16.3±2.5
70-80	20.0±3.5	15.4±2.8	19.4±2.9	21.9±3.4	13.6±2.2	14.0±2.3
80-90	16.9±3.2	16.4±2.9	13.8±2.4	13.9±2.7	9.5±1.9	12.5±2.2
90-100	25.6±4.0	13.9±2.7	14.2±2.5	16.0±2.9	10.6±2.0	10.6±2.0
100-110	20.0±3.5	13.9±2.7	11.2±2.2	17.6±3.1	8.4±1.8	10.2±2.0
110-120	18.1±3.4	13.4±2.6	9.9±2.1	15.0±2.8	9.5±1.9	7.2±1.7
120-130	14.4±3.0	15.4±2.8	12.5±2.3	11.2±2.4	8.4±1.8	10.6±2.0
130-140	13.7±2.9	11.8±2.5	5.2±1.5	9.6±2.3	7.0±1.6	9.1±1.9
140-150	15.0±3.1	7.7±2.0	5.2±1.5	8.6±2.1	7.0±1.6	4.2±1.3
150-160	5.6±1.9	7.7±2.0	1.7±0.9	3.2±1.3	3.3±1.1	3.0±1.1
160-170	1.2±0.9	5.7±1.7	2.6±1.1	3.7±1.4	0.0±0.4	2.3±0.9
170-180	0.6±0.6	1.5±0.9	0.4±0.4	0.5±0.5	0.4±0.4	1.1±0.7

$\theta_n^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	90-95	95-100	100-110	110-120	120-130	130-140
0-10	0.0±0.3	1.6±0.6	0.2±0.2	0.2±0.1	0.2±0.1	0.2±0.1
10-20	3.0±1.0	1.6±0.6	1.3±0.4	0.5±0.2	0.6±0.2	0.7±0.2
20-30	6.7±1.5	4.5±1.0	2.3±0.5	1.5±0.4	1.8±0.4	1.0±0.2
30-40	10.0±1.8	6.5±1.2	3.8±0.7	2.8±0.5	2.7±0.4	1.5±0.3
40-50	10.0±1.8	8.3±1.4	4.7±0.7	2.6±0.5	2.4±0.4	2.2±0.3
50-60	9.0±1.7	9.0±1.4	4.2±0.7	4.3±0.6	3.8±0.5	2.4±0.4
60-70	13.0±2.1	9.4±1.5	4.8±0.8	3.5±0.6	3.0±0.5	1.6±0.3
70-80	15.0±2.2	8.5±1.4	3.7±0.7	5.1±0.7	2.7±0.4	2.0±0.3
80-90	16.0±2.3	7.4±1.3	4.3±0.7	2.9±0.5	2.1±0.4	1.7±0.3
90-100	7.3±1.6	5.8±1.1	3.9±0.7	2.9±0.5	1.9±0.4	1.5±0.3
100-110	8.3±1.7	6.3±1.2	1.9±0.5	2.2±0.4	1.2±0.3	0.9±0.2
110-120	7.7±1.6	4.3±1.0	3.0±0.6	1.1±0.3	1.3±0.3	0.9±0.2
120-130	6.0±1.4	3.6±0.9	1.4±0.4	0.5±0.2	1.4±0.3	0.5±0.2
130-140	4.3±1.2	3.4±0.9	1.7±0.4	1.3±0.3	0.4±0.2	0.6±0.2
140-150	3.7±1.1	1.3±0.5	1.4±0.4	1.0±0.3	0.9±0.3	0.7±0.2
150-160	1.7±0.7	1.1±0.5	0.7±0.3	0.3±0.2	0.4±0.2	0.5±0.2
160-170	0.7±0.5	0.2±0.2	0.5±0.2	0.2±0.1	0.4±0.2	0.1±0.1
170-180	1.0±0.6	0.2±0.2	0.4±0.2	0.5±0.2	0.1±0.1	0.2±0.1

**T a b l e 2:  ${}^4\text{He}(\gamma, p){}^3\text{H}$  reaction**

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	22-23	23-24	24-25	25-26	26-27	27-28
0-10	5.8±1.9	3.0±1.8	2.2±1.6	4.6±1.7	7.3±2.7	4.6±2.3
10-20	17.3±3.3	20.3±4.5	22.3±5.0	17.2±3.4	17.6±4.3	23.1±5.2
20-30	40.4±5.1	56.8±7.6	42.4±6.9	58.9±6.2	62.2±8.0	57.8±8.2
30-40	75.7±7.0	96.4±9.9	81.4±9.5	76.7±7.1	105.7±10.5	78.6±9.5
40-50	103.9±8.2	135.9±11.7	104.8±10.8	109.8±8.5	141.9±12.1	120.3±11.8
50-60	148.1±9.7	156.2±12.6	131.5±12.1	134.9±9.4	161.6±12.9	164.2±13.8
60-70	149.4±9.8	184.6±13.7	172.8±13.9	155.4±10.1	198.9±14.4	163.0±13.7
70-80	162.9±10.2	195.8±14.1	170.6±13.8	182.5±11.0	226.9±15.3	197.7±15.1
80-90	186.6±10.9	239.4±15.6	198.4±14.9	181.9±11.0	211.3±14.8	187.3±14.7
90-100	175.1±10.6	229.3±15.2	188.4±14.5	164.7±10.4	195.8±14.2	188.5±14.8
100-110	155.8±10.0	193.7±14.0	169.5±13.7	163.4±10.4	185.4±13.9	133.0±12.4
110-120	152.6±9.9	148.1±12.3	152.7±13.0	136.9±9.5	161.6±12.9	143.4±12.9
120-130	119.3±8.7	144.0±12.1	133.8±12.2	113.8±8.7	126.4±11.4	91.3±10.3
130-140	99.4±8.0	92.3±9.7	94.8±10.3	77.4±7.2	86.0±9.4	75.2±9.3
140-150	62.2±6.3	58.8±7.7	58.0±8.0	58.9±6.2	70.4±8.5	55.5±8.0
150-160	38.5±5.0	29.4±5.5	37.9±6.5	21.2±3.7	31.1±5.7	27.8±5.7
160-170	14.1±3.0	17.2±4.2	16.7±4.3	13.9±3.0	10.4±3.3	17.3±4.5
170-180	4.5±1.7	7.1±2.7	5.6±2.5	3.3±1.5	5.2±2.3	6.9±2.8

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	28-29	29-30	30-31	31-32	32-33	33-34
0-10	10.3±3.4	6.8±2.8	3.6±2.1	3.9±1.7	6.7±2.2	9.0±2.8
10-20	24.1±5.3	27.1±5.5	25.0±5.4	22.4±4.2	23.0±4.1	17.1±3.9
20-30	44.8±7.2	57.7±8.1	65.4±8.8	52.6±6.4	49.0±6.0	54.0±7.0
30-40	74.7±9.3	106.3±11.0	89.1±10.3	75.1±7.6	86.8±8.0	63.8±7.6
40-50	132.2±12.3	133.5±12.3	145.0±13.1	140.1±10.4	128.4±9.8	117.8±10.3
50-60	156.4±13.4	191.1±14.7	185.4±14.8	160.2±11.1	150.6±10.6	130.4±10.8
60-70	178.2±14.3	193.4±14.8	173.5±14.4	160.2±11.1	172.1±11.3	147.5±11.5
70-80	201.2±15.2	158.3±13.4	185.4±14.8	152.4±10.9	181.8±11.6	146.6±11.5
80-90	180.5±14.4	209.2±15.4	186.6±14.9	146.3±10.6	166.2±11.1	140.3±11.2
90-100	163.3±13.7	166.3±13.7	158.0±13.7	147.0±10.7	151.4±10.6	115.1±10.2
100-110	143.7±12.9	149.3±13.0	152.1±13.4	130.8±10.1	109.8±9.0	101.6±9.6
110-120	131.1±12.3	132.3±12.2	108.1±11.3	107.6±9.1	102.4±8.7	93.5±9.2
120-130	102.3±10.8	105.2±10.9	80.8±9.8	82.0±8.0	81.6±7.8	73.7±8.1
130-140	64.4±8.6	76.9±9.3	76.1±9.5	67.3±7.2	59.4±6.6	45.9±6.4
140-150	59.8±8.3	56.6±8.0	45.2±7.3	41.8±5.7	43.0±5.7	48.6±6.6
150-160	42.5±7.0	26.0±5.4	26.1±5.6	34.8±5.2	18.6±3.7	28.8±5.1
160-170	13.8±4.0	10.2±3.4	8.3±3.1	11.6±3.0	10.4±2.8	7.2±2.5
170-180	2.3±1.6	3.4±2.0	2.4±1.7	7.7±2.4	5.9±2.1	3.6±1.8

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	34-35	35-36	36-37	37-38	38-39	39-40
0-10	11.1±3.3	4.5±2.0	7.1±2.7	6.5±2.7	3.7±2.1	8.6±3.3
10-20	21.1±4.6	16.4±3.9	25.5±5.1	13.0±3.8	15.9±4.4	12.4±3.9
20-30	39.2±6.3	58.2±7.3	42.8±6.6	34.7±6.1	50.1±7.8	48.2±7.7
30-40	68.4±8.3	86.4±8.9	63.2±8.0	74.8±9.0	74.5±9.5	50.7±7.9
40-50	97.6±9.9	102.8±9.7	86.6±9.4	97.6±10.3	108.8±11.5	85.3±10.3
50-60	110.7±10.6	132.8±11.0	105.0±10.3	110.6±11.0	97.8±10.9	111.2±11.7
60-70	123.8±11.2	148.3±11.6	122.3±11.2	104.1±10.6	103.9±11.3	87.7±10.4
70-80	125.8±11.3	124.6±10.6	106.0±10.4	129.0±11.8	122.2±12.2	107.5±11.5
80-90	133.8±11.6	133.7±11.0	130.4±11.5	111.7±11.0	92.9±10.7	86.5±10.3
90-100	106.7±10.4	165.6±12.3	94.8±9.8	91.1±9.9	88.0±10.4	81.6±10.0
100-110	85.5±9.3	109.2±10.0	81.5±9.1	70.5±8.7	74.5±9.5	76.6±9.7
110-120	69.4±8.4	71.0±8.0	73.4±8.6	67.2±8.5	59.9±8.6	59.3±8.6
120-130	72.8±8.5	61.9±7.5	42.8±6.6	53.1±7.6	39.1±6.9	42.0±7.2
130-140	52.3±7.3	51.9±6.9	37.7±6.2	55.3±7.7	25.7±5.6	30.9±6.2
140-150	37.2±6.1	35.5±5.7	27.5±5.3	18.4±4.5	18.3±4.7	16.1±4.5
150-160	36.2±6.0	22.7±4.5	9.2±3.1	11.9±3.6	25.7±5.6	12.4±3.9
160-170	10.1±3.2	7.3±2.6	7.1±2.7	9.8±3.3	1.2±1.2	2.5±1.7
170-180	7.0±2.7	3.6±1.8	2.0±1.4	4.3±2.2	1.2±1.2	3.7±2.1

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	40-41	41-42	42-43	43-44	44-46	46-48
0-10	3.4±2.4	4.5±2.6	3.5±2.5	4.6±2.7	6.6±3.8	4.1±1.8
10-20	8.4±3.8	16.4±5.0	10.6±4.3	20.1±5.6	13.3±5.4	9.0±2.7
20-30	47.1±8.9	28.4±6.5	24.7±6.6	40.3±7.9	24.3±7.3	27.7±4.8
30-40	52.2±9.4	52.3±8.8	47.7±9.2	49.6±8.8	44.2±9.9	43.2±5.9
40-50	52.2±9.4	85.2±11.3	61.8±10.4	66.6±10.2	64.1±11.9	55.4±6.7
50-60	77.4±11.4	85.2±11.3	88.3±12.5	71.3±10.5	50.9±10.6	73.3±7.7
60-70	87.5±12.1	80.7±11.0	86.5±12.4	93.0±12.0	73.0±12.7	79.0±8.0
70-80	67.3±10.6	88.2±11.5	77.7±11.7	97.6±12.3	70.8±12.5	76.6±7.9
80-90	94.3±12.6	79.2±10.9	70.6±11.2	71.3±10.5	64.1±11.9	68.4±7.5
90-100	72.4±11.0	62.8±9.7	56.5±10.0	85.2±11.5	50.9±10.6	67.6±7.4
100-110	65.6±10.5	67.3±10.0	51.2±9.5	55.8±9.3	35.4±8.8	57.0±6.8
110-120	50.5±9.2	37.4±7.5	35.3±7.9	48.0±8.6	46.4±10.1	34.2±5.3
120-130	45.4±8.7	41.9±7.9	45.9±9.0	49.6±8.8	31.0±8.3	27.7±4.8
130-140	26.9±6.7	43.4±8.1	26.5±6.8	20.1±5.6	13.3±5.4	23.6±4.4
140-150	15.1±5.0	22.4±5.8	17.7±5.6	27.9±6.6	15.5±5.9	16.3±3.6
150-160	16.8±5.3	10.5±4.0	10.6±4.3	7.7±3.5	2.2±2.2	10.6±2.9
160-170	3.4±2.4	4.5±2.6	8.8±3.9	4.6±2.7	2.2±2.2	6.5±2.3
170-180	3.4±2.4	3.0±2.1	5.3±3.1	6.2±3.1	4.4±3.1	4.9±2.0

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	58-60	60-62	62-64	64-66	66-68	68-70
0-10	0.0±0.9	0.6±0.6	0.6±0.6	0.7±0.7	0.0±0.6	1.1±0.8
10-20	6.8±2.4	5.8±1.8	8.9±2.4	5.8±2.0	1.2±0.8	3.8±1.5
20-30	10.3±3.0	16.9±3.1	9.5±2.5	13.8±3.2	10.0±2.4	11.0±2.5
30-40	18.0±3.9	23.3±3.7	29.9±4.4	18.1±3.6	18.8±3.3	8.8±2.2
40-50	35.1±5.5	26.2±3.9	29.9±4.4	25.3±4.3	20.6±3.5	14.8±2.9
50-60	35.1±5.5	27.9±4.0	28.6±4.3	24.6±4.2	22.9±3.7	21.4±3.4
60-70	37.6±5.7	33.1±4.4	22.3±3.8	33.3±4.9	33.5±4.4	19.2±3.3
70-80	36.8±5.6	29.7±4.2	29.9±4.4	33.3±4.9	32.3±4.4	34.6±4.4
80-90	30.8±5.1	25.0±3.8	20.4±3.6	34.0±5.0	25.8±3.9	22.0±3.5
90-100	32.5±5.3	23.3±3.7	24.8±4.0	22.4±4.0	9.4±2.3	15.9±3.0
100-110	17.1±3.8	14.5±2.9	11.5±2.7	17.4±3.5	9.4±2.3	17.0±3.1
110-120	18.0±3.9	16.9±3.1	15.9±3.2	10.1±2.7	11.2±2.6	11.0±2.5
120-130	12.0±3.2	10.5±2.5	8.3±2.3	7.2±2.3	7.6±2.1	6.0±1.8
130-140	12.8±3.3	12.2±2.7	5.1±1.8	5.8±2.0	5.3±1.8	7.7±2.1
140-150	6.8±2.4	4.7±1.6	4.5±1.7	9.4±2.6	2.3±1.2	4.4±1.6
150-160	6.0±2.3	4.7±1.6	1.9±1.1	4.3±1.8	2.9±1.3	1.1±0.8
160-170	0.9±0.9	1.2±0.8	1.9±1.1	1.4±1.0	1.8±1.0	2.7±1.2
170-180	0.0±0.9	0.6±0.6	0.6±0.6	0.7±0.7	2.3±1.2	0.5±0.5

$\theta_p^*, \text{deg}$	$E_\gamma, \text{MeV}$					
	70-72	72-74	74-76	76-78	78-80	80-85
0-10	0.5±0.5	1.1±0.8	1.0±0.7	0.0±0.4	0.9±0.7	0.3±0.3
10-20	3.8±1.4	4.5±1.6	3.0±1.2	3.7±1.2	4.3±1.4	4.6±1.2
20-30	8.7±2.2	10.0±2.4	8.5±2.1	8.2±1.8	9.0±2.1	5.9±1.4
30-40	16.9±3.0	11.2±2.5	13.5±2.6	9.1±1.9	11.8±2.4	7.9±1.6
40-50	16.9±3.0	16.2±3.0	15.0± 2.7	14.0±2.4	19.4±3.0	12.4±2.0
50-60	20.7±3.4	21.2±3.4	20.5±3.2	17.3±2.7	17.0±2.8	11.5±1.9
60-70	21.8±3.4	24.0±3.7	21.0±3.2	19.0±2.8	24.1±3.4	17.0±2.4
70-80	24.0±3.6	22.3±3.5	17.5±3.0	13.2±2.3	18.5±3.0	11.8±2.0
80-90	18.5±3.2	21.8±3.5	22.0±3.3	13.6±2.4	17.0±2.8	9.2±1.7
90-100	16.9±3.0	19.0±3.3	15.0±2.7	12.8±2.3	17.5±2.9	9.5±1.8
100-110	14.7±2.8	14.0±2.8	9.0±2.1	7.4±1.7	9.5±2.1	6.9±1.5
110-120	14.2±2.8	6.1±1.9	12.0±2.5	8.7±1.9	11.8±2.4	6.9±1.5
120-130	9.3±2.2	12.8±2.7	8.0±2.0	7.4±1.7	3.3±1.3	6.9±1.5
130-140	5.4±1.7	9.5±2.3	7.0±1.9	6.2±1.6	4.3±1.4	4.6±1.2
140-150	3.3±1.3	6.7±1.9	5.5±1.7	4.9±1.4	1.9±0.9	3.3±1.0
150-160	2.7±1.2	2.8±1.2	5.5±1.7	3.3±1.2	1.4±0.8	1.3±0.7
160-170	3.3±1.3	1.7±1.0	0.5±0.5	2.9±1.1	2.8±1.2	1.3±0.7
170-180	0.0±0.5	1.7±1.0	0.5±0.5	0.8±0.6	0.5±0.5	0.0±0.3



$\theta_p^*, \text{deg}$	$E_\gamma, \text{ MeV}$						
	85-90	90-95	95-100	100-110	110-120	120-130	130-140
0-10	0.6±0.5	0.9±0.5	0.0±0.2	0.8±0.3	0.2±0.1	0.1±0.1	0.1±0.1
10-20	2.6±0.9	1.6±0.7	2.7±0.8	1.1±0.4	0.9±0.3	0.3±0.1	0.4±0.1
20-30	6.8±1.5	5.0±1.2	5.4±1.1	2.5±0.6	1.6±0.4	1.1±0.3	1.4±0.3
30-40	6.5±1.4	7.5±1.5	6.8±1.2	4.1±0.7	2.6±0.5	2.1±0.4	1.8±0.3
40-50	10.0±1.8	9.9±1.8	7.4±1.3	5.3±0.8	3.5±0.6	2.1±0.4	1.5±0.5
50-60	16.5±2.3	15.5±2.2	7.9±1.3	5.6±0.9	3.4±0.6	2.9±0.4	2.6±0.4
60-70	12.9±2.0	13.4±2.0	9.7±1.5	5.9±0.9	3.7±0.6	2.4±0.4	2.2±0.3
70-80	13.2±2.1	13.0±2.0	11.3±1.6	4.5±0.8	3.9±0.6	3.1±0.4	2.0±0.3
80-90	12.0±2.0	10.9±1.8	7.0±1.3	4.1±0.7	3.6±0.6	1.9±0.3	1.7±0.3
90-100	9.0±1.7	7.1±1.5	6.1±1.2	3.6±0.7	2.9±0.5	1.7±0.3	1.4±0.3
100-110	8.4±1.6	6.8±1.5	5.0±1.1	2.4±0.6	1.6±0.4	1.3±0.3	1.0±0.2
110-120	6.5±1.4	7.8±1.6	3.2±0.8	3.5±0.7	1.7±0.4	0.9±0.2	0.8±0.2
120-130	3.6±1.1	6.5±1.4	5.2±1.1	1.7±0.5	0.8±0.3	0.6±0.2	0.5±0.2
130-140	5.2±1.3	2.5±0.9	1.8±0.6	1.3±0.4	1.2±0.3	0.8±0.2	0.4±0.1
140-150	3.9±1.1	3.4±1.0	2.0±0.7	1.9±0.5	1.0±0.3	0.5±0.2	0.4±0.1
150-160	1.0±0.6	1.2±0.6	0.9±0.5	0.7±0.3	0.4±0.2	0.2±0.1	0.5±0.2
160-170	0.6±0.5	0.6±0.4	0.5±0.3	0.1±0.1	0.3±0.2	0.1±0.1	0.3±0.1
170-180	0.3±0.3	1.2±0.6	0.7±0.4	0.1±0.1	0.2±0.1	0.4±0.1	0.1±0.1